Evaluating Crown Fire Rate of Spread from Physics Based Simulations with Field Data.

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Introduction

- Fire behavior models provide a means to test our understanding of systems and allow us to explore the interactions among objects
  - Functions of models: Synthesis, Prediction and Informing and guiding observation and experimentation

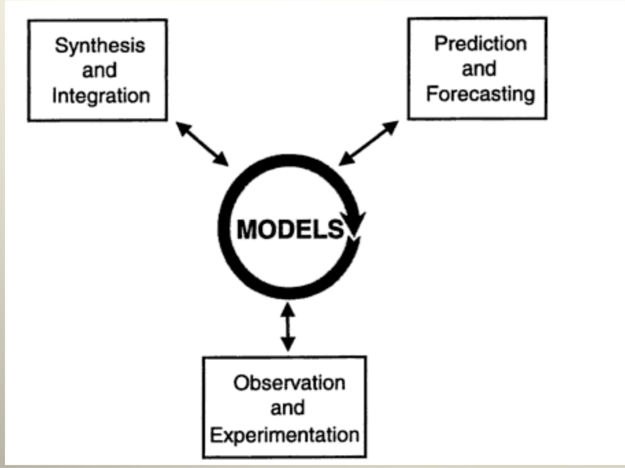


Fig. 1. The three roles of models in natural resources and ecosystem sciences.
Canham et al. 2003

Objectives

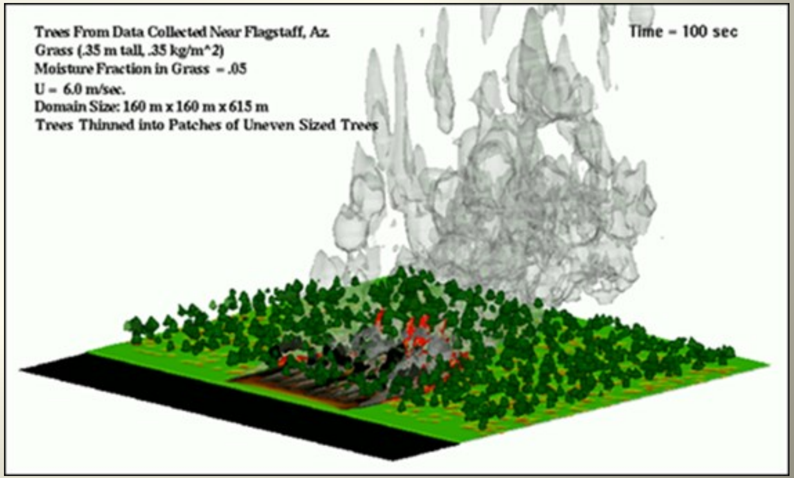
- The focus of this work is on assessing the appropriateness of 2 physics based models for the prediction of crown fire spread
  - 2 physics based models:
    - FIRETEC – developed at Los Alamos National Lab
    - WFDS – Developed at the National Institute of Standards and technology

Background

- FIRETEC and WFDS:
  - Use numerical methods to solve a coupled set partial differential equations that govern multi-phase fluid flow and combustion.
  - Simulate vegetation as a porous medium with mean or bulk quantities such as the vegetation surface area to volume ratio, moisture content and bulk density within the 3D grid

Background

- This approach allows for:
  - The three dimensional nature (heterogeneity) of the fuels complex to be approximated
  - Includes the coupled dynamics among the fire, vegetation and atmosphere
  - Result in spatial and temporal predictions of various quantities of interest….



Background and problem

- WFDS and FIRETEC have gone through verification processes
- The set of equations for the resolved aspects are well accepted and have be evaluated for a wide variety of applications….

However there is limited evaluation against field scale wildfire data and virtually none for crown fires

lots of ongoing work

Methods: AC06 data set

- Alexander and Cruz (2006) compiled a total of 57 (43 from Canada, 14 from U.S.) wildfire observations from North American forests.
  - Original intent of the data set was to evaluate an empirical model of crown fire spread (Cruz et al. 2005)
    - Cases that lacked adequate data, occurred in fuel types that do not support crown fire, or in areas with complex topography (>10% slope, or cross slope fire spread) were removed from the compiled data set

Methods: AC06

- For each case AC06 reported:
  - major fuel type,
  - the ambient temperature (°C),
  - the relative humidity (%),
  - the effective fine fuel moisture (%)*
  - the Canopy Bulk Density (kg m-3) (CBD)**
  - the 10 m open wind speed (km h-1)***

*inferred the CBD using a variety of methods on a case-by-case basis
** adjusted the 6.1 meter open wind speed for all data from the U.S. by a factor of 15% to approximate the 10-m open wind speed
***estimated the effective fine fuel moisture content using equations published by Rothermel (1983)

Methods: Simulated crown fire rates of spread

- We identified simulations conducted with WFDS an FIRETEC that:
  - Were in North American and European forest types that experience crown fires,
  - Reported both the 10-m open wind speed and the crown fire ROS,
  - Had at least 25% crown fuel consumption and
  - Simulated fire spread over at least 2 hectares
  - Did not include complex topography

Methods: Simulated Crown Fire spread

- A total of 65 simulations were identified:
  - 32 conducted using WFDS
  - 33 conducted with FIRETEC

Table 2. Source of the physics-based modeling data used in comparisons. The fuel types are as follows: PP—Ponderosa Pine, LPP—Lodge Pole Pine, PJ—Piñon and Juniper, BS—Black Spruce, AP—Aleppo Pine.

Data source	Fuel type	Model used	Number of simulations
Seig (2014)	PP	FIRETEC	1
Hoffman et al. (2014)	LPP	FIRETEC	2
Linn et al. (2013)	PJ	FIRETEC	4
Linn et al. (2012a)	BS	FIRETEC	20
Linn et al. (2005b)	PP	FIRETEC	4
Pimont et al. (2011)	AP	FIRETEC	1
Ziegler (2014)	PP	WFDS	32

Analysis

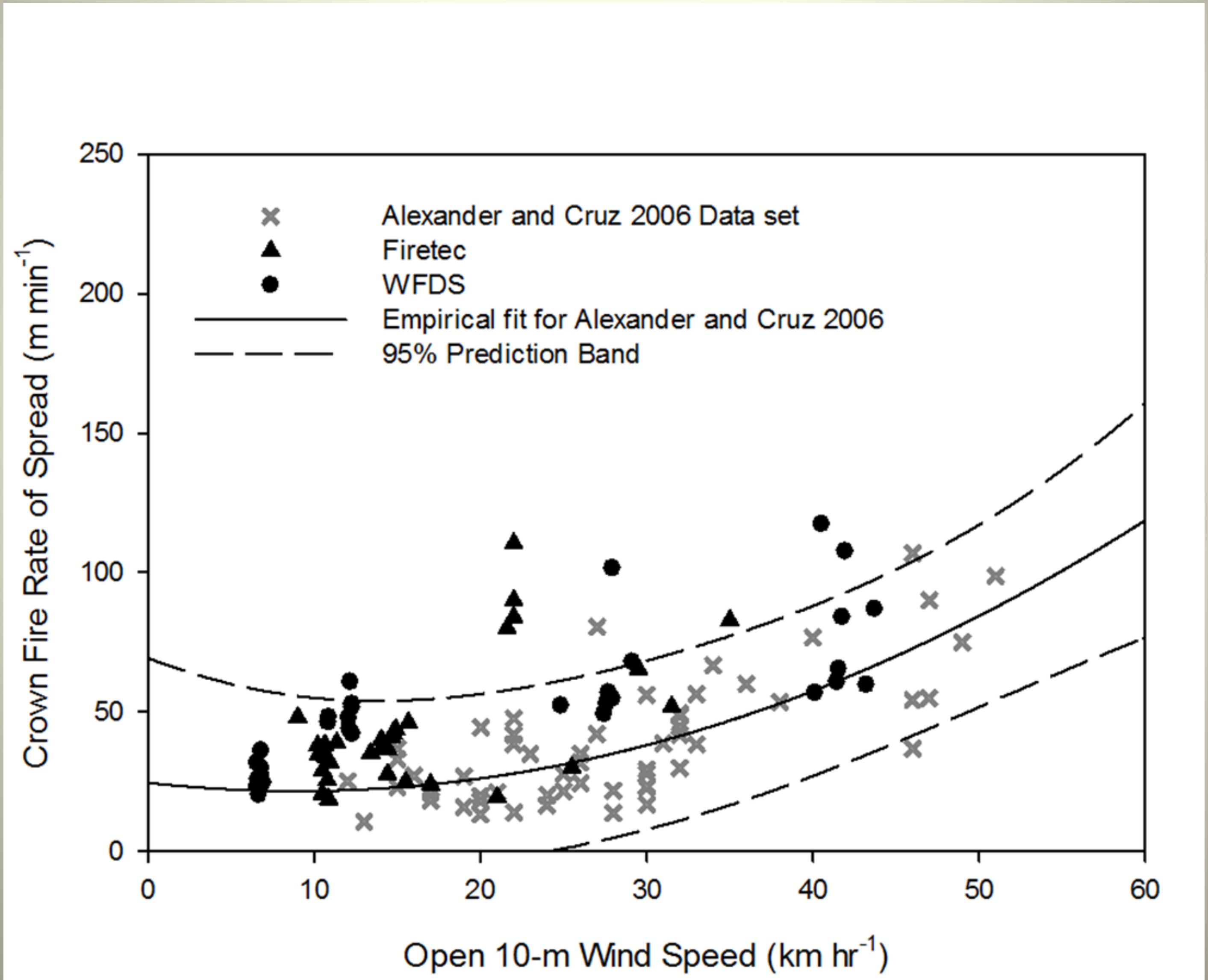
- used linear regression methods to assess the relationship between the 10-m open wind speed and the crown fire ROS and estimated non-simultaneous 95% prediction bounds for a new observation.
  - Our final regression was:

$$CROS=24.5+(0.669*10U)+((0.0373*10U)^2) \qquad \text{Eq.1}$$

    - Where: CROS is the crown fire rate of spread and 10U is the open 10m wind velocity.

- Compared the simulated crown fire ROS from FIRETEC and WFDS to the 95% prediction bounds and assessed the number of points for each model that fell within the prediction bounds.

Results


Alexander and Cruz 2006 Data set
Firetec
WFDS
Empirical fit for Alexander and Cruz 2006
95% Prediction Band
Crown Fire Rate of Spread (m min^{-1})
Open 10-m Wind Speed (km hr^{-1})
0
50
100
150
200
250
0
10
20
30
40
50
60

Results

	WFDS	FIRETEC
Number of simulated fires	32	33
Range of 10m wind velocities (km hr-1)	4-35.3	6.5-43.7
Forest type	PP	BS, PJ, LPP, PP
number of points outside 95% prediction bands	4	5
% of points outside of 95% prediction bands	12.5%	15.2%
% over prediction	100%	100%
% under prediction	0%	0%

Results: Outlier cases

- FIRETEC
  - 4 of 5 outliers from FIRETEC are likely due to the use of a constant (no shear) wind profile.
    - Other point was from a simulation in Pinion Juniper woodlands.

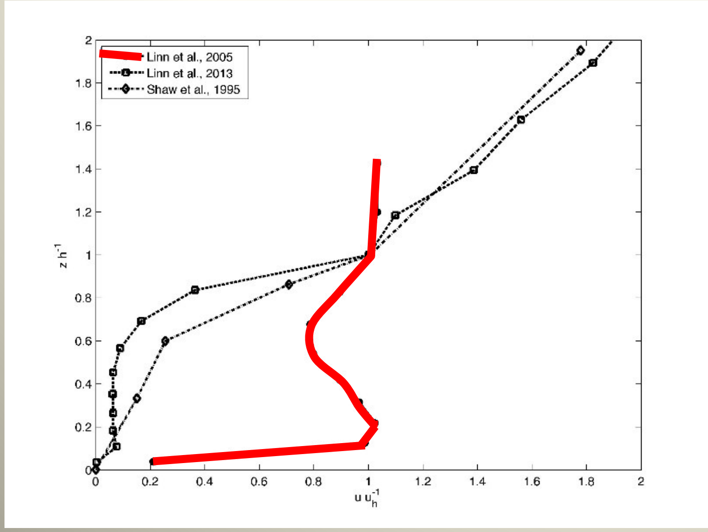
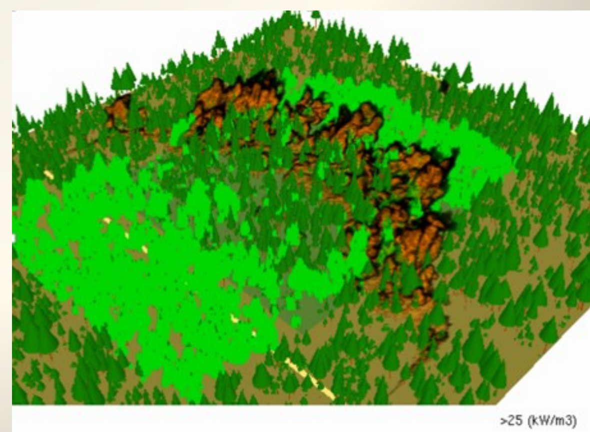


Figure 3. Canopy wind profiles from FIRETEC simulations from Linn et al. 2005, Linn et al. 2013 and measured wind profile from Shaw et al. 1995.

Results: Outlier cases

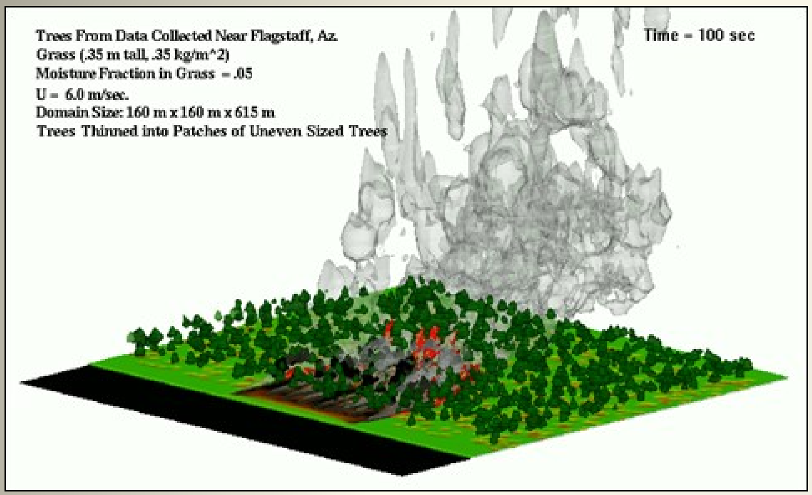
- All WFDS outliers were populated with data from a single location.
  – It is difficult to identify the mechanisms responsible for the over predictions in these cases due to a lack of details regarding the independent data.

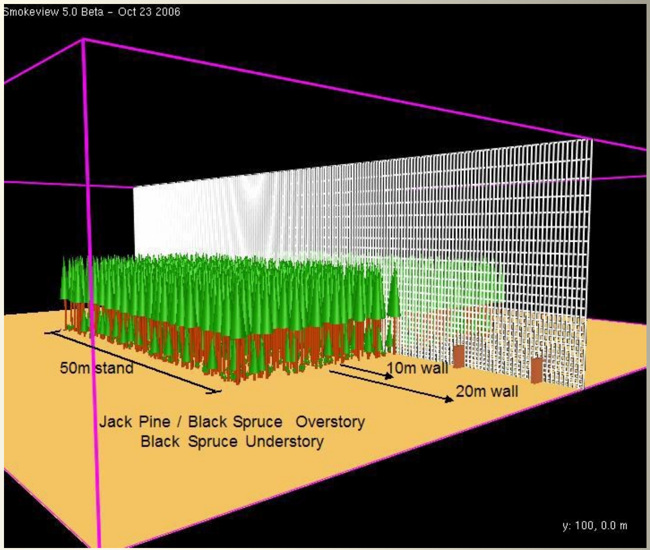


Discussion

- Both WFDS and FIRETEC provide crown fire rate of spread predictions within the range expected for a given open wind speed
- Lack of detailed observations and uncertainties in the observational data available
  - limits the assessment of predictive power from physics based models
  - However – we need to continue to try and make these kinds of comparisons, model improvements will occur when we find differences….

Questions


Trees From Data Collected Near Flagstaff, Az.
Grass (.35 m tall, .35 kg/m^2)
Moisture Fraction in Grass = .05
U = 6.0 m/sec.
Domain Size: 160 m x 160 m x 615 m
Trees Thinned into Patches of Uneven Sized Trees
Time = 100 sec


Smokeview 5.0 Beta - Oct 23 2006
50m stand
10m wall
20m wall
Jack Pine / Black Spruce Overstory
Black Spruce Understory
y: 100, 0.0 m

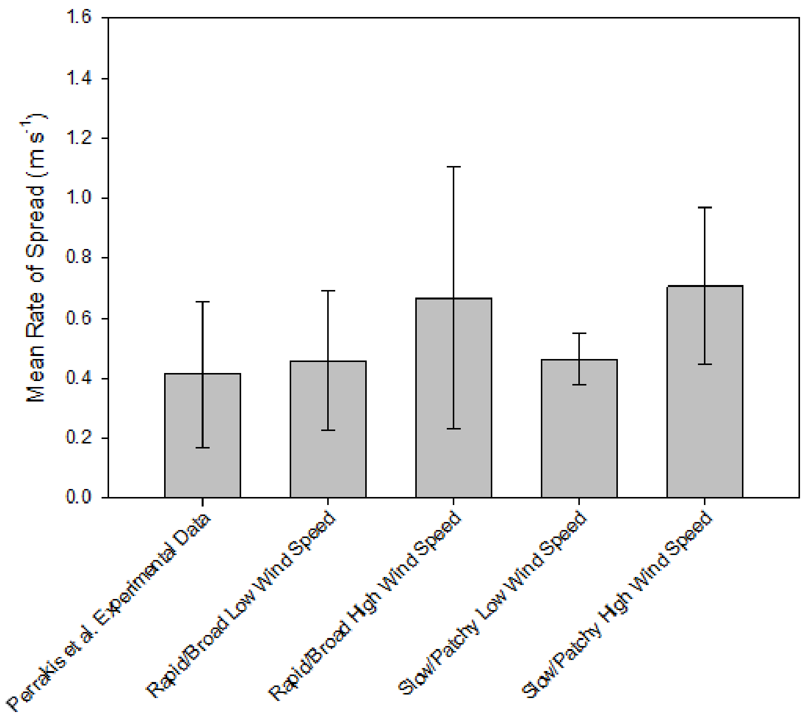


Fig. 12. Comparison of rate-of-spread predictions for our Rapid/Broad and Slow/Patchy low and high wind speed scenarios from FIRETEC to experimental data from 14 fires in mountain pine beetle-infested forests (Perrakis et al. 2014).